REMOTE SENSING OF COMETARY DUST AND COMPARISONS TO IDPS.

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Comets are the best link we have to the composition of the primitive solar nebula. They have remained relatively unaltered since their formation in the outer, colder parts of the solar nebula.

IN SITU SAMPLING

We have in situ sampling of the. dust composition of only one comet, from the impact ionization time-of-flight mass spectrometer on the Halley probes (Kissel et al 1986). The composition of the major rock-forming elements is chondritic within a factor of two, but the comet dust is enriched in the elements H, C, N, O compared to carbonaceous chondrites, implying that the dust is more volatile- rich and more "primitive" (Jessberger et al 1988). Within the so-called CHON particles, there is a wide spread in the abundance. ratios, a result that is not consistent with the proposal that there is a refractory organic component consisting mainly of polyoxymethelenes. Among silicate. particles, the Fe/(Fe+Mg) ratio ranges from 0 to 1, with Mg-rich silicates predominating. The wide. distribution of Fe/(Fe+Mg) does not agree with the. narrow range measured in carbonaceous chondrites, but does resemble anhydrous IDPs (Lawler et al 1989).

INFRARED SPECTROSCOPY

Infrared spectroscopy is the best means of remotely studying the composition of cometary solids. The spectra can help to establish links to interstellar grains and to identify classes of interplanetary dust particles likely to originate from comets. Transitions within various organic molecules produce features in the 3 μm region, while the 10 μm spectral region contains information about the mineral content of the grains.

A. Spectral Features from Organic Molecules

A broad emission feature at 3.36 μm was discovered in Comet Halley (Fig. 1). (Combes et al 1986; Wickramasinghe & Allen 1986; Knacke et al 1986; Baas et al 1986; Danks et al 1987). It has subsequently been detected in every bright come! observe.d in the 3 μm region (Allen & Wickramasinghe 1987; Brooke et al 1989, 1990, 1991; Davies et al 1991; Green et al 1991). The feature is generally assigned to a C-1 I stretch vibration, but it is not obvious from the shape of the feature. whether it originates in the gas or in small grains. The detailed structure varies among comets, with secondary peaks at 3.28 pm, 3.41 μm, and 3.52 μm having differing strengths relative to the main 3.36 μm peak; the 3.28 pm peak is particularly visible in the long period comet Levy 1990 XX (Davies et al 1991). The 3.28 μm peak resembles one of the set of unidentified infrared bands seen in H 11 regions, planetary nebulae, and a few young stellar objects, but there is no analogous 3.36 μm emission feature in any astronomical source (Tokunaga and Brooke 1990).

Because the feature is seen in both new and evolved comets, it can not be the result of cosmic ray irradiation of ices in the outer few meters of Oort Cloud comets. Brooke et al (1991) demonstrated that the strength of the 3.36 μm band emission correlates better with the gas production rate than with the dust continuum, implying a gas phase carrier. The 3.52 μm feature is consistent with the ν_3 band of methanol (CH_3OH) (Hoban et al 1991), But methanol also has bands at 3.3 -3.4 pm. Reuter (1991) has computed the contribution of methanol to the main 3.36 μm feature. Depending on how one. normalizes the 3.S2, pm feature, the accompanying contribution to the 3.36 μm feature ranges from 10 - 50 %. 'J'bus, the spectral shape and the heliocentric distance dependence of the residual "unidentified" 3.36 pm feature may be somewhat different from the total observed flux and wc arc back to the question whether the carrier is in the gas or solid phase.

B. Silicates

A broad emission feature near 10 μm is observed in intermediate bandpass filter photometry of most dynamically new and long-period comets (Ney 1982, Gehrz & Ney 1992). The strength of the feature is quite variable, being strongest in "dust rich" comets with strong scattered light continuum. The 10 pm emission feature is most likely due to the. Si-O stretching mode vibration in small silicate particles. 1 ile.mental abundances indicative

Of silicates were common in particles detected by the dust mass spectrometer during the Halley flybys and silicate grains are a major component of interplanetary dust particles. The spectral matches with IDPs and other silicate sample.s are reasonable.

Spectra at 8-13 μm with high signal/noise now exist for eight comets. Four are dynamically new comets, that is, thought to be coming in from the Oort cloud for the first time, two are long-period comets, and two (Halley and Brorsen-Metcalf) have periods ~70 years. (These 8 spectra will be analyzed in more detail in Hanner, Lynch & Russell 1993,)

The spectrum of Comet Halley is shown in Figure 2, from Campins & Ryan (1989). There is a broad maximum at 9.8 μm and a narrower peak at 11.25 pm. A Halley spectrum by Bregman et al (1987) showed similar structure. The 11.25 μm peak agrees with that seen in olivine IDPs (Sandford & Walker 1985), as illustrated in Figure 2, and crystalline olivine is the probable source of the cometary peak, Other possible explanations for the peak at 11.25 μm, such as SiC or an organic, component can be ruled from the width of the peak, abundance arguments, or for lack of corresponding feature.s, such as the 7,7 and 8.6 μm features present when an 11.3 μm feature is associated with the set of unidentified interstellar emission bands. Two long period comets, Bradfield 1987 XXIX and Levy 1990 XX have similar double-peaked spectra (Lynch et al 1989; Hanner et al 1990; Lynch et al 1992). Levy's spectrum is shown in Figure 3.

Koike et al (1993) have obtained infrared transmission spectra of olivine samples with differing Mg/Fe abundance. They find that the peak lies at 11.3 pm for Mg/(Mg+Fe) = 0.9 and shifts toward 11.5 μm as the Mg abundance decreases. The 11.25 μm position in the comets implies a high Mg/Fe abundance, a conclusion consistent with the dust analyses from the Halley probes (Jessberger et al 1988; Lawler et al 1989).

However, another component must give rise to the broad maximum near 9.8 pm. There are three main possibilities (Hanner et al 1990).

1. Mix of crystalline minerals: The IDPs examined by Sandford & Walker (1985) can be classified by their 10 μm transmission spectra as olivines, pyroxenes, or hydrated silicates. Bregman et al (1987) were able to fit their Halley spectrum with a mix of these three grain types. This approach has the advantage of relating the comet dust directly to IDPs. However, not all of these grain types necessarily originate from comets, as discussed further at this Workshop.

2. Glassy silicates: Interstellar silicate grains are thought to be amorphous because of their broad, structureless 10 μm feature. From the emission spectra measured by Stephens & Russell (1979), amorphous olivine can explain the 9.8 μm cometary peak, while a mixture of amorphous olivine and amorphous enstatite can account for the rise between 8 and 9 pm. This explanation is attractive because it requires the least alteration of interstellar silicates before their incorporation into comets. Bradley et al (1992) have now identified a component of glassy silicate particles among the chondritic IDP's. Their spectrum of a thin

section of a glass-rich I 1>1' resembles the comet spectra.

3. I lydrated silicates: Type 11 carbonaceous chondrites have about equal proportions of hydrated silicates and olivine. '1'heir spectra actually look rather similar to the comet spectra (Zaikowski, Knacke, & Porco 1975). Nelson, Nuth, and Dorm (1987) suggested that amorphous silicate grains on the surface of a comet nucleus could absorb onc or more mono olayers of water molecules from the outflowing gas and could be converted to hydrated silicates if exposed to temperatures of 300 K or above for a few weeks. Yet, the silicate feature was strongest in 1 Ialley at times of strong jet activity when the silicate dust appeared to be emanating from deep vents in the nucleus, rather than the surface. Moreover, the. Mg/Fe/Si distribution in carbonaceous chondrites dots not resemble the 1 Ialley dust (1 .awler et al 1989).

Of the 4 new comets for which good quality spectra arc available, each has a unique spectrum that differs from that seen in Comets I Ialley, Bradfield, and I .evy. Kohoutek (Merrill 1974) has a strong emission feature similar to that in Halley, except that the 11.3 μm peak is lacking. Wilson, 1987 VII (1 .ynch et al 1 989) showed a broader emission feature with an unidentified peak at 12.2 pm. Okazaki-I .evy-Rudenko 1989 XIX (Russell & I .ynch 1990) had a weak feature with a maximum between 10.5 -11,5 μm, while Austin 1990 V (Hanner et al 1993) showed a weak feature with a possible small peak at 11.1 μm (Figure 4). Comets OLR and Austin were both dust-poor comets, based on the strength of their scattered and thermal continuum radiation; that is, the total dust cross-section was low, but not necessarily the total dust mass, if the dust is concentrated in larger particles.

P/Brorsen-Metcalf showed the danger of generalizing. With a 70,6 year period and perihelion at 0.48 AU, P/Brorsen-Metcalf has an orbit similar to that of P/Halley and one might have expected their spectra to be similar. Yet, l}rorscn-Metcalf showed no emission feature at all in six clays of observing (1 .ynch et al 1992).

Clearly, then, there is not a single kind of "cometary" silicate dust. Our sample of comets is too small to generalize about the characteristics of ncw versus evolved comets. Spectra of onc or more "dusty" ncw comets will be n eeded before we can conclude whether small crystalline olivine grains are ever present in ncw comets,

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REFERENCES

Allen, D. & Wickramasinghe, D. 1987. Nature 329, 615.

Baas, F., Geballe, '1'. R., & Walther, D.M. 1986. Astrophys. J. 311, 1.97.

Bradley, J, 1'., Humecki, 11. J. & Germani, M. S. 1992. Astrophys. J. 394, 643.

Bregman, J., Campins, H., Witteborn, F.C., Wooden, D.H., Rank, D. M., Allamandolla, L. J., Cohen, M. & Tielens, A. G. G.M. 1987, Astron. Astrophys. 187, 616.

Brooke, T. Y., Knacke, R. F., Owen, T.C. & Tokunaga, A.T. 1989. Astrophys. J. 336, 971.

Brooke, T. Y., Tokunaga, A.”]’. & Knacke, R.F. 1991. Astron. J. 101, 268.

Brooke, T.Y., Tokunaga, A.T., Knacke, R.F., Owen, ‘I’, C., Mumma, M. J., Reuter, D., & Storrs, A.D. 1990. Icarus 83,434.

Campins, H. & Ryan, E.V. 1989. Astrophys. J. 341, 1059,

Combes, M. et al 1986, Nature 321,266.

Danks, A. C., Encrenaz, T., Bouchet, P., Le Bertre, T. & Chalabaev, A. 1987. Astron. Astrophys. 184, 329.

Davies, J. K., Green, S.F. & Geballe, “1’.1{. 1991. MNRAS 251, 148.

Gehrz, R.D. & Ney, E.P. 1992. Icarus 100, 162.

Green, S.F., Davies, J, K., Geballe, ‘1’. R., Brooke, ‘I’. Y., & Tokunaga, A.T. 1992. Asteroids, Comets, Meteors 1991, p 211.

Hanner, M. S., Lynch, D. K. & Russell, R, W. 1993, in preparation.

Hanner, M. S., Newburn, R.]., Gehrz, R.D., Harrison, ‘J’., Ney, E.P. & Hayward, “1’.1,. 1990. Astrophys. J. 348, 312.

Hanner, M. S., Russell, R. W., Lynch, D. K. & Brooke, T. Y. 1993. Icarus 101, 64.

Hoban, S., Mumma, M., Reuter, D. C., DiSanti, M. 1991. Icarus, 93, 122.

Jessberger, E.K., Christoforidis, A. & Kissel, J. 1988. Nature 332, 691.

Kissel, J. et al 1986. Nature 321, 2,80, 336.

Knacke, R.F., Brooke, T.Y. & Joyce, R.R. 1986. Astrophys. J. 310, I A9.

Koike, C., Shibai, H. & Tuchiyama, A. 1993. MNRAS, in press.

Lawler, M. E., Brownlee, D.E., Temple, S. & Wheelock, M.M. 1989. Icarus 80, 225.

Lynch, D. K., Hanner, M.S. & Russell, R.W. 1992. Icarus, 97, 269.

Lynch, D. K., Russell, R. W., Hackwell, J. A., Hanner, M.S. & Hammel, H.B. 1992. Icarus 100, 197.

Lynch, D. K., Russell, R. W., Witteborn, F. C., Bregman, J., Rank, D. & Cohen, M. 1989. Icarus 82, 379.

Merrill, K. M. 1974. Icarus 23, 566.

Nelson, R., Nuth, J.A. & Donn, B. 1987. Proc. 17th Lunar Plan. Sci. Conf. JGR 92 p E657.

Ney, E.P. 1982. In Comets, ed. L.L. Wilkening (Tucson: University of Arizona Press), p. 323,

Reuter, D.C. 1992. Astrophys. J. 386, 330.

Russell, R. W. & Lynch, D. K. 1990. in Workshop on Recent Comets, ed. Huebner, Rahe, Wehinger, Konno, Albuquerque, p. 92,

Sandford, S.A. & Walker, R.M. 1985. Astrophys. J 291, 838.

Stephens, J .R. & Russell, R.W. 1979. Astrophys. J 228, 780.

Tokunaga, A. T. & Brooke, T. Y. 1990. Icarus 86 208.

Wickramasinghe, D. & Allen, D. 1986. Nature 323, 44.

Zaikowski, A., Knacke, R.F. & Porco, C.C. 1975. Astrophys. Space Sci. 35, 97.

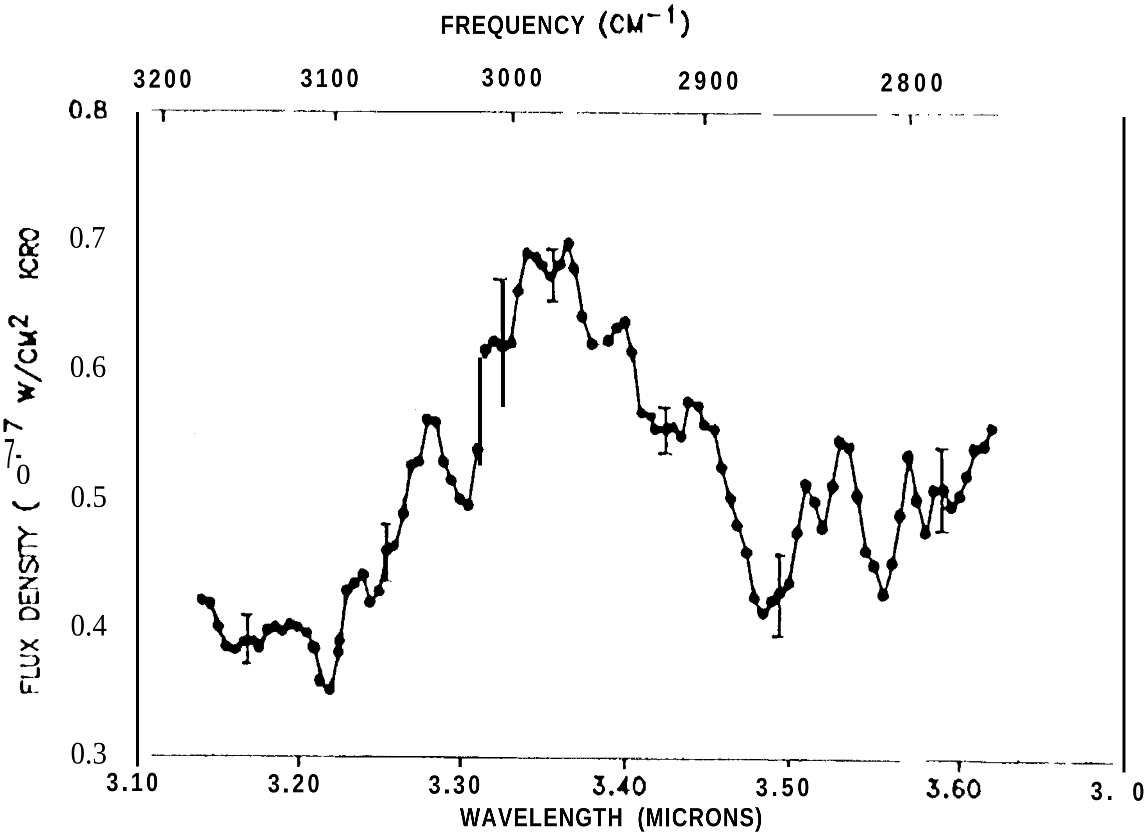

Fig. 1. 3μm spectrum of Comet P/Halley on 25 April 1986 at r=1.54 AU (Baas et al 1986).

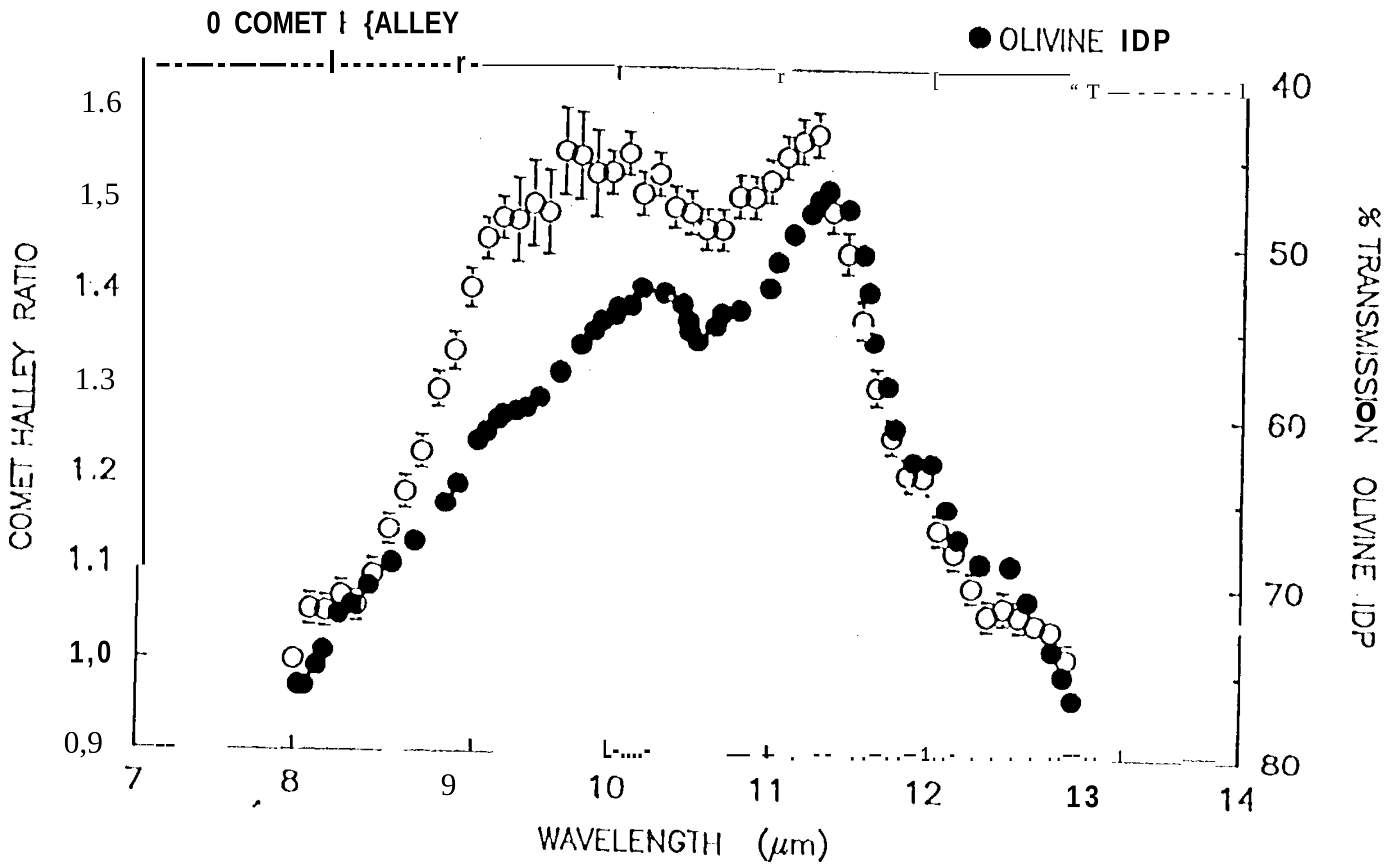

Fig. 2. 8-13 μm spectrum of Comet Halley at r=0.79 AU (Campins & Ryan 1989) compared with olivine IDP (Sandford & Walker 1985).

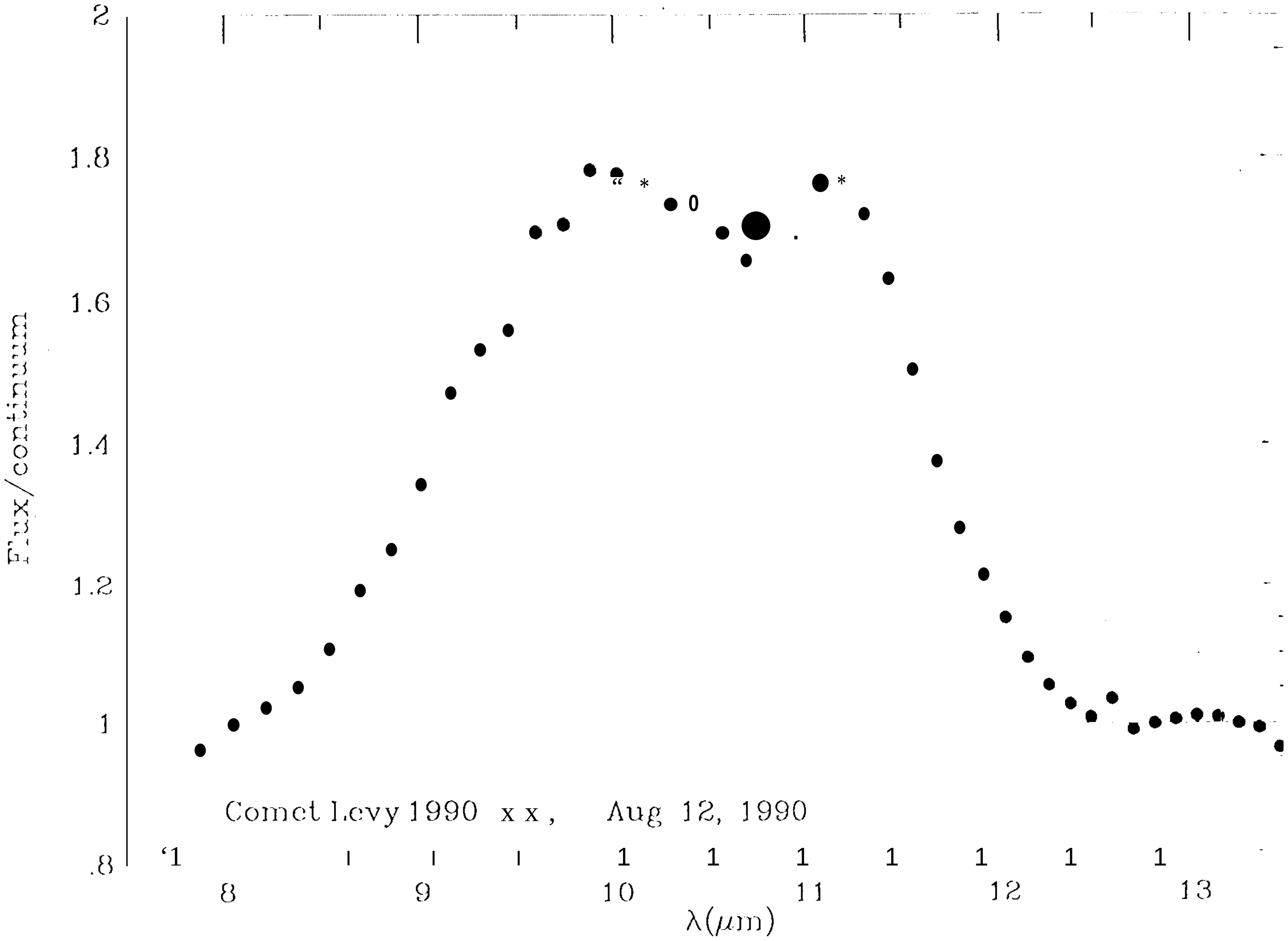

Fig. 3. 8-13 μm spectrum of Comet Levy 1990 XX at r= 1.S6 AU perihelion (Lynch et a] 1992). The total flux has been divided by 270 K blackbody continuum.

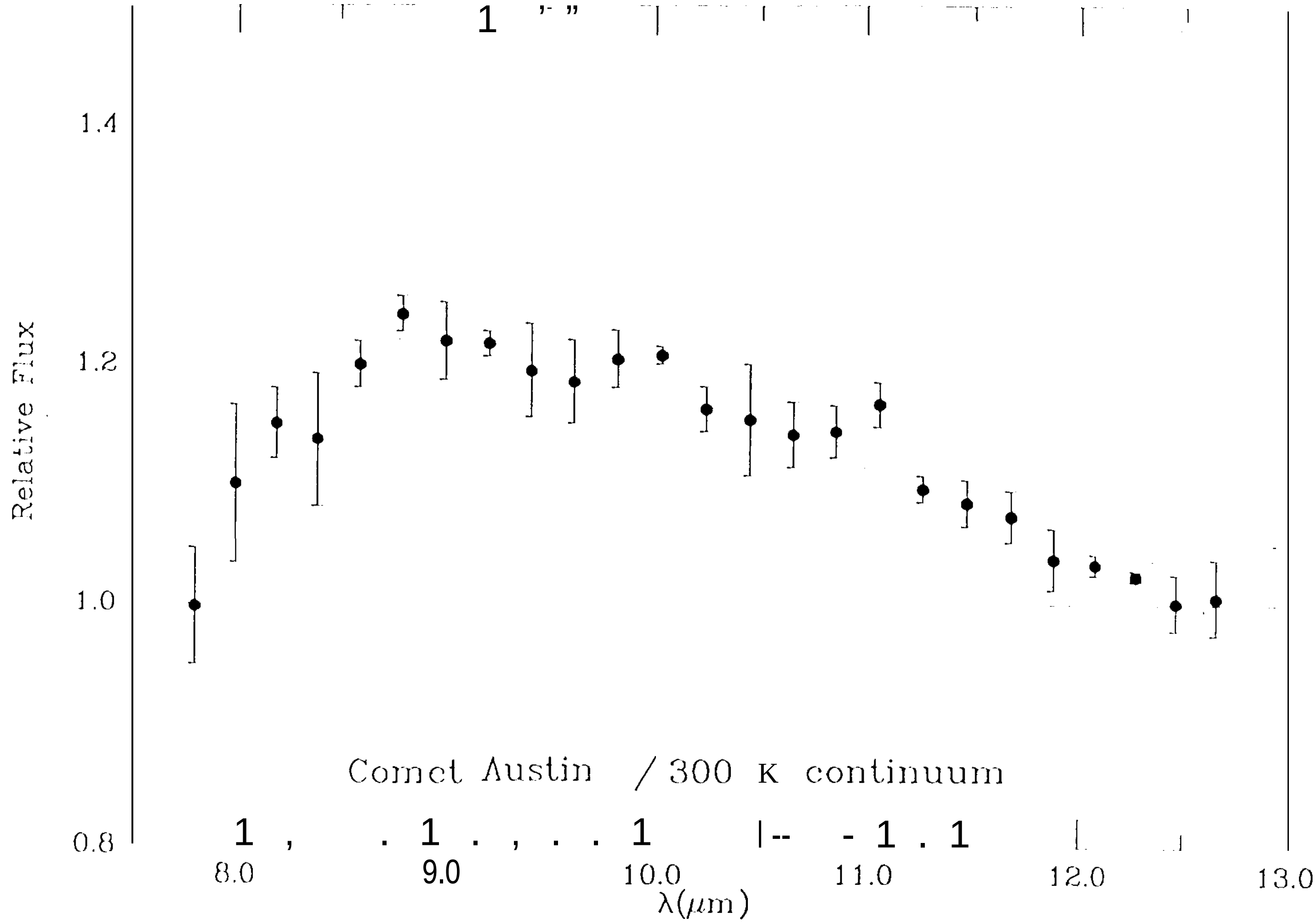

Fig. 4. 8-13 pm spectrum of Comet Austin 1990 V at r=0.78 AU (1 Ianner et al 1993). The observed flux has been divided by 300 K blackbody continuum.